

## CHAPTER 6

### STONE TESTING

6-1. General. Stone testing is part of the investigation of sources but involves laboratory testing and other methods sufficiently distinct to warrant separate consideration in this chapter.

a. Physical testing and examination are important in two or more separate ways. First, the direct preview of physical characteristics and behavior of the stone material is useful in planning and design. Second, some contract specifications are stated in terms of these physical properties, and the properties may reemerge again as important to construction inspection. The determination of which methods and tests are most revealing of stone quality must incorporate considerations of loading to be imposed, climatic conditions, and severity of exposure of the stone in the project area. For example, freezing and thawing effects are important considerations in the northern regions. Attention usually focuses on visual characteristics, unit weight, and porosity, and on durability against abrasion and wetting and drying as well as freezing and thawing. Standard tests according to ER 1110-1-2005, Handbook for Concrete and Cement, Rock Testing Handbook, and American Society for Testing and Materials are preferred, but simple, rapid and much less formal methods of evaluation are also useful and sometimes even more revealing than standard tests.

b. Methods appropriate to evaluate large stone may vary from region to region, for example, cold versus warm regions. Generally, some of the testing should simulate the critical environmental factors. However, even methods developed initially to evaluate small stone for concrete aggregate have been useful (EM 1110-2-2000). Poor results from testing of aggregate abrasion can hardly be explained as other than indicative of poor stone, regardless of the intended purpose of the stone. For this particular test, the problems come in the converse, since good abrasion test results may indicate unrepresentative sampling rather than good stone (paragraph 4-8a). Since no single test is satisfactory for predicting the performance of all stone types, it is usually best to apply a combination of tests based partly on local experience.

c. Nonapproval of locally available stone usually increases project costs since stone meeting the requirements may have to be hauled from another source at a substantial distance. As a check, compare the test results against service records and results of the field examination. Using good judgment guided by test results as well as all other information is usually the appropriate strategy for avoiding unnecessary costs.

6-2. Laboratory Methods. Laboratory testing is ordinarily accomplished by or under supervision of the Government. The factors in sampling material for testing are discussed in paragraph 4-8. In choosing testing methods, try to represent important design or environmental aspects. More than one test method is usually necessary. The ranges of acceptable test values in Table 6-1 should be regarded as broad generalizations still needing verification or adjustments for local experience. Test procedures are in accordance with methods in the Handbook for Concrete and Cement unless indicated otherwise.

Table 6-1. Criteria for Evaluating Stone

Test	Approximate Criterion for Suitability*
Petrography	Fresh, interlocking crystalline, with few vugs, no clay minerals, and no soluble minerals
Unit Weight	Dry unit weight 160 lb/cu ft or greater
Absorption	Less than 1 percent
Sulfate Soundness	Less than 5 percent loss
Glycol Soundness	No deterioration except minor crumbs from surface
Abrasion	Less than 20 percent loss for 500 revolutions
Freezing-Thawing	Less than 10 percent loss for 12 cycles
Wetting-Drying	No major progressive cracking
Field Visual	Distinctions based on color, massiveness, and other visual characteristics
Field Index	Distinctions based on scratch, ring, and other physical characteristics
Drop Test	No breakage or cracking
Set Aside	No breakage or cracking after one season cycle

\* Marginal test results usually indicate the need for supplemental testing for definitive evaluation.

a. Petrography.

(1) While petrographic examination is often essential for evaluating the suitability and potential durability of large stone, it is limited to qualitative rather than quantitative appraisal. Petrographic examination identifies the composition and homogeneity of samples and their general physical condition and should recognize potential parting planes. Although the existing method CRD-C 127 is directed to petrographic examination of concrete aggregates rather than large stone, useful guidance can be found under its ledge rock category. The American Society for Testing and Materials (ASTM) designation is C 295. Beyond that guidance, one should emphasize flaws that may be found in large stones. Accordingly, samples selected at the source should include flaws common to large stone that is or will be produced. Supplemental descriptive information should be supplied to aid the petrographer in giving a total evaluation of the rock for its intended use.

(2) Among special methods for studying large stones are polishing, etching, and staining of cut slabs. Serious defects identifiable in these

ways are platiness, shaliness, slabiness, and a tendency to slake. Potential for such defects may be present in the form of clay seams, bedding, fractures and joints, rounded or planar surfaces, nodules, and indications of weathering or chemical alteration. High-quality stone sometimes exhibits an interlocking fabric and absence of bedding. A useful technique is to wipe the rough or cut stone with a wet cloth to emphasize defects.

b. Stone Density. Intrinsic properties of stone related to its mass or density are important in design: unit weight, specific gravity, and absorption. Appropriate test methods are found in CRD-C 107. Tests are usually conducted on scraps remaining after slabs have been cut for other tests.

(1) Specific Gravity. Care should be exercised in using specific gravity to characterize stone since only the solid components (mineralogical) are considered in true specific gravity. However, the terms "apparent specific gravity" and "bulk specific gravity (saturated, surface-dry basis)", adapted from aggregate testing, are entrenched in past experience, and any departure, regardless of its sensibility, may introduce ambiguity. Carefully defining and limiting such terms in the specifications is essential to avoiding ambiguity. A more useful parameter sometimes is dry unit weight in which the important parameter porosity is included. However, specific gravity of solids must be determined for calculating porosity unless specific gravity of solids can be estimated confidently from the petrographic analysis.

(2) Unit Weight. The overall stone density is conveniently characterized in terms of dry unit weight to take account of porosity as well as mineral density. Commonly used rock types range from about 140 to 160 lb/cu yd. There is a tendency for rocks with dry unit weight exceeding 160 lb/cu yd to be among the least troublesome. Toward and below the low end of the common range, the durability of stone tends to decrease as a reflection of increasing porosity.

(3) Absorption. A portion of rock porosity functions to draw water in from the surface by absorption. Absorption of water is a common precursor of stone deterioration, and the absorption test is particularly useful for revealing vulnerability. Absorption values exceeding two percent generally suggest potential durability problems. Values in the range from one to two percent are common among suitable and unsuitable stone materials alike and, therefore, these values are less diagnostic. Absorption below one percent usually indicates stone of good quality.

c. Soundness. Tests which subject the rock to severe chemical treatments are intended to reveal weaknesses in a shortened time frame. The dissimilarity in comparison to natural weathering is sometimes a source of concern in translating laboratory results into estimates of stone performance. Both tests below are relatively simple and inexpensive.

(1) Magnesium Sulfate. Standardized testing follows CRD-C 137, a method developed for evaluating aggregate. Samples soaked in a sulfate solution will break apart when the solution invades weak planes or cracks and then crystallizes upon heating and drying. A major shortcoming of this test for large stone is that the test specimens are broken from the large stone to a weight of approximately 100 g each. The breakage and segregation will eliminate weak areas when preparing the sample, and test results tend to be too

favorable. Nevertheless, a loss exceeding 10 percent generally indicates poor-quality stone. The test is usually meaningful for sedimentary rocks when augmented by an absorption or abrasion test, except for some sandstones.

(2) Ethylene Glycol. Standardized testing follows CRD-C 148. This method is used to detect the presence of swelling clay minerals and provides an indication of the severity of deterioration of the stone to be expected in service. Ethylene glycol enters the clay mineral structure and causes rapid expansion. The test has been particularly useful in distinguishing questionable varieties among altered basaltic rocks.

d. Abrasion. The Los Angeles abrasion test follows method CRD-C 145. The test is useful in determining the resistance of stone to abrasion and battering and also provides an index of toughness, durability, and abundance of incipient cracks. The significance of the test for large stone is indefinite since individual test pieces are limited to about 100 g in weight. Weaknesses along widely spaced surfaces are missed in this test. Roughly, losses less than 20 percent for 500 revolutions are generally considered satisfactory while losses exceeding 40 percent suggest probable poor service. The test is sometimes effective for evaluating metamorphic rock, particularly when supported by absorption and sulfate soundness tests.

e. Freezing-Thawing.

(1) The standard method follows CRD-C 144, but modifications for large slabs cut perpendicular to bedding or for whole large stones are preferred by some laboratories because of better representation. Large-stone testing is discussed at length in Evaluation of Quality and Performance of Stone as Riprap or Armor. Regardless of details, a consistency in procedure is desirable, at least within a division laboratory and its service area. The test simulates the effects of a cold environment by inducing numerous cycles of freezing and thawing through a bath of water and alcohol. Again, the number of cycles to which the specimen is subjected and the overall interpretation of the results should be determined on a district or laboratory basis. The number of cycles commonly exceeds 10, occasionally going to 50 or more, depending upon local climate or established method. Failures along weak surfaces should be given special attention since their impact is easily underestimated.

(2) For small pieces wherein bedding and jointing are insignificant, a loss of 10 percent by test CRD-C 144 should cause concern. Large stones and slabs losing more than 25 percent during 12 cycles will probably not perform well in service. Large stones losing no more than 10 percent commonly do perform satisfactorily. The effects of geological structure and other important characteristics of a material are less likely to be overlooked when at least three specimens are tested simultaneously in the same test bath.

f. Wetting-Drying. Testing large stone for wetting and drying effects generally follows division-level guidance since no standard method is recognized nationally. A method suitable for testing large stone has been proposed in Evaluation of Quality and Performance of Stone as Riprap or Armor. No generally applicable experiences are available correlating quantitative test results and stone service in place. Considerable judgment has to be exercised even in descriptions of scaling and flaking, random cracking, and slabbing

along bedding and similar fabric. Photographs are especially helpful in characterizing the rock and its behavior in regard to deterioration.

g. Other Tests. Tests other than those mentioned above could prove helpful in distinguishing stone suitable for large-stone construction. These tests usually involve inexpensive and quick methods for determining index properties. They include tests for compressive strength, Schmidt rebound, and water content. Preferences usually reflect experience and satisfactory results within an individual district or division.

6-3. Field Methods. Field methods include numerous tests and techniques that can be conducted quickly and inexpensively. Some of the tests provide on-the-spot evaluation and are suitable for QA. However, visual inspection and simple field tests ordinarily should not be considered as conclusive in regard to acceptability of stone.

a. Visual Examination.

(1) The visual examination of rock in the field corresponds in some ways to the petrographic analysis in the laboratory but without the benefit of equipment for preparation and detailed examination. The lack of sophisticated equipment is sometimes more than balanced by the large volume of material available for examination. The visual examination in the field is not limited to the stones in a face pile or stockpile but should include rock in place.

(2) The specific features of most interest are clay seams, bedding, fractures and joints, rounded or planar surfaces, deleterious materials, chert nodules, and indications of weathering or chemical alteration. Frequently, important observations can be made on durability by comparing the features and conditions of stone in the face with features in freshly blasted and stockpiled or wasted stone from operations months or years in the past. The suitability of the material for size and gradation is a high-priority question distinguished separately in paragraph e. below.

(3) The important product of a visual inspection in the field is an adequate documentation of observations. Descriptions and maps will ordinarily be included in a report for the quarry file along with test results and photographs.

b. Index Tests. Index tests may be performed in the field where the necessary testing equipment is easily portable. The choice of index test generally reflects the experience of the district. Schmidt rebound is an example of an index easily extended to field usage; however, its basic usefulness is not well established. Even a parameter as simple as scratch hardness can be formulated into usefulness where numerous values roughly distinguish subtle variations within rock otherwise appearing to be uniform. Color is another potentially useful index parameter; for example, brownish gray tones occasionally distinguish slightly weathered stone from fresher rock with straight gray tones.

c. Drop Test.

(1) A drop test provides an immediate evaluation of the suitability of very large stone material and is also potentially useful for quality control

and QA. For comparability, the test stone(s) should be dropped from a bucket or cherry picker, or by other means from a height half the average diameter of the stone onto a rigid surface or second stone of comparable size. Dumping with other stones from a haulage truck is usually unsatisfactory practice.

(2) The stone should be examined carefully before testing as well as afterward. Failure criteria are development of new cracks, opening of old cracks, and loss of small pieces from the surface.

d. Set Aside. The set-aside test is a particularly good method of forewarning of future problems with stone deterioration. Typically, large stones are set aside in the quarry and immediately examined and photographed. These specimens are examined and photographed again after a predetermined period of exposure. Stone that endures without signs of deterioration may be considered for acceptance. Observations from set-aside exposure are potentially useful in identifying materials in need of curing. The one disadvantage of this test is the long exposure period required, that is, preferably a year or more.

e. Stone Size Count. Careful measurements of stone size and gradation are appropriate for evaluating a quarry or later for evaluating the suitability of stone destined for the project. Estimates short of actual counting or measuring individual stones should be questioned for accuracy. The preferred measuring technique for large stones in the sample is with a tape or caliper and a scale. It may be appropriate to screen or grizzly the smaller stones. Gradation is quantified by weight in each size class or stone by stone on a cumulative basis.

f. Fill Density. The unit weight of the stone material in place is a particularly important parameter bearing on strength, settlement, and drainage of rockfill embankments. Test fill investigations (paragraph 5-5) use fill density as a key criterion for confirmation of design and selection of suitable construction methods, but the test is also useful for spot checking placement. Five steps are involved.

(1) Place 6-ft diameter steel ring or other template on a level surface of the fill.

(2) Remove stone material inside to the depth of interest, leaving the wall of the hole undisturbed.

(3) Weigh all material removed in a dry condition.

(4) Line hole with flexible impermeable sheet and fill to the surface with a measured volume of water.

(5) Calculate the unit weight from the weight and volume in (3) and (4) above.

6-4. Test Blasting. Trial or test blasting constitutes large-scale testing to confirm or demonstrate that an unproven source and quarry methods are capable of producing the desired large-stone products. Confirmation comes through stone counts by size and with visual examination of the product. Several portions of the source may be tested to demonstrate uniformity over a

large area. Variations in blasting patterns and techniques may also be investigated. Test blasting may be undertaken by contract or elsewhere may be on the initiative of the contractor or stone producer.

6-5. Reporting Results. Material is accepted or rejected largely on the basis of test results and geological characteristics. Accordingly, the results need to be organized and reported with care. The following are helpful in organizing reports.

a. Standard Forms. Where available, use forms established for reporting the results of testing by standard methods. Supplemental information may also be appropriate.

b. Raw Data. Work sheets should be preserved in files for ready reference.

c. Evaluation. Test reports should provide the test results completely and in a form to facilitate evaluation by others later. The evaluation and supporting interpretations by the district should be clearly distinguished from laboratory testing and results.

d. Comparisons. The testing laboratory is in the position to make a useful comparison of results with past results of testing similar stone. In this way the experience and judgment of the staff are passed along for consideration.

e. Summarization. A summary of test results is helpful where extensive raw data and work sheets have been included in the report.

6-6. Evaluation Criteria. The use of testing criteria to evaluate stone materials is complex and should proceed with great care, especially when dealing with new sources or new portions of old sources. The evaluation should come after completion of testing and examination and reporting of results. Guidance on possible testing criteria is provided in paragraphs 6-2 and 6-3 as part of the explanations of the test methods. These numerous generalized criteria are also summarized in Table 6-1. Exceptions to the criteria are so plentiful that the criteria provide little more than first estimates of stone performance that may or may not prove valid within a region. Their principal value comes when evaluations based on test criteria reinforce other indications and thus increase confidence in judgmental decisions in planning and contracting.